Interactive effects of deficit irrigation and vermicompost on yield, quality, and irrigation water use efficiency of greenhouse cucumber

Halimeh PIRI[1*], Amir NASERIN[2], Ammar A ALBALASMEH[3]

1 Department of Water Engineering, Faculty of College of Water and Soil, University of Zabol, Zabol 9861335856, Iran;
2 Department of Water Engineering, Agricultural Sciences and Natural Resources University of Khuzestan, Mollasani 6341773637, Iran;
3 Department of Natural Resources and the Environment, Faculty of Agriculture, Jordan University of Science and Technology, Irbid 22110, Jordan

Abstract: Water scarcity is the most significant barrier to agricultural development in arid and semi-arid regions. Deficit irrigation is an effective solution for managing agricultural water in these regions. The use of additives such as vermicompost (VC) to improve soil characteristics and increase yield is a popular practice. Despite this, there is still a lack of understanding of the interaction between irrigation water and VC on various crops. This study aimed to investigate the interaction effect of irrigation water and VC on greenhouse cucumber yield, yield components, quality, and irrigation water use efficiency (IWUE). The trials were done in a split-plot design in three replicates in a semi-arid region of southeastern Iran in 2018 and 2019. Three levels of VC in the experiments, i.e., 10 (V_1), 15 (V_2), and 20 t/hm² (V_3), and three levels of irrigation water, i.e., 50% (I_1), 75% (I_2), and 100% (I_3) of crop water requirement were used. The results showed that the amount of irrigation water, VC, and their interaction significantly affected cucumber yield, yield components, quality, and IWUE in both years. Reducing the amount of irrigation water and VC application rates reduced the weight, diameter, length, and cucumber yield. The maximum yield (175 t/hm²) was recorded in full irrigation using 20 t/hm² of VC, while the minimum yield (98 t/hm²) was found in I_1V_1 treatment. The maximum and minimum values of IWUE were recorded for I_1V_3 and I_3V_1 treatments as 36.07 and 19.93 kg/(m³•hm²), respectively. Moreover, reducing irrigation amount decreased chlorophyll *a* and *b*, but increased vitamin C. However, the maximum carbohydrate and protein contents were obtained in mild water-stressed conditions (I_2). Although adding VC positively influenced the value of quality traits, no significant difference was observed between V_2 and V_3 treatments. Based on the results, adding VC under full irrigation conditions leads to enhanced yield and IWUE. However, in the case of applying deficit irrigation, adding VC up to a certain level (15 t/hm²) increases yield and IWUE, after which the yield begins to decline. Because of the salinity of VC, using a suitable amount of it is a key point to maximize IWUE and yield when applying a deficit irrigation regime.

Keywords: irrigation water use efficiency; greenhouse; size and weight of fruit; soil amendment; semi-arid region

Citation: Halimeh PIRI, Amir NASERIN, Ammar A ALBALASMEH. 2022. Interactive effects of deficit irrigation and vermicompost on yield, quality, and irrigation water use efficiency of greenhouse cucumber. Journal of Arid Land, 14(11): 1274–1292. https://doi.org/10.1007/s40333-022-0035-7

---

*Corresponding author: Halimeh PIRI (E-mail: H_piri2880@uoz.ac.ir)
Received 2022-05-31; revised 2022-10-12; accepted 2022-10-28

1 Introduction

Nowadays, deficit irrigation is used as a reassuring tool for boosting the yield of crops through the available water resources (Geerts and Raes, 2009). In addition to enhancing water use efficiency, this strategy leads to the increased area under cultivation because of creating additional water resources. Despite this increased efficiency, deficit irrigation could cause water stress in the root zone, resulting in a decrease in the yield. Nevertheless, water shortage in plants does not necessarily occur due to deficit irrigation, and sometimes this shortage develops because of environmental stresses. Based on climate condition and plants, researchers employed various solutions to mitigate the effect of stress. Furthermore, mitigation of water stress effects for different plants has also been studied previously using chemical (Piri and Naserin, 2020; Piri and Naserin, 2022), and biological fertilizers (El-Mageed et al., 2018). In this way, supplementary nutrients are essential for continuous cultivation, especially in greenhouse. However, long-term usage of chemical fertilizers can pollute the ecosystem, resulting in groundwater contamination and soil physical and chemical damage.

Organic matter is a fraction of soil critical for enhancing soil's physical, chemical, and biological properties, particularly in arid and semi-arid regions. The properties of organic matters added to the soil including the type, amount, and size are significant determinants for affecting the soil (Nelson and Oades, 1998), and the yield (Celestina et al., 2019). Despite the proven advantages of organic matters instead of inorganic mineral fertilizers in agricultural lands, farmers are not very interested in using organic matters in the farm (Hijbeek et al., 2018) due to various reasons. In addition, many biological wastes still fail to change into compost. For example, in Europe, only around one-third of this type of wastes is used as compost (Meyer-Kohlstock et al., 2015).

Vermicompost (VC) is a type of compost produced by worms in reaction to the transformation, conversion, and relative digestion of organic wastes and plant residues as they move through the worm's digestive systems. The presence of humic and organic matters in VC stimulates plant growth better than feeding the plant with mineral fertilizers (Atiyeh et al., 2001a). Utilization of VC as soil amendment causes improved permeability and drainage of soil as well as, by preserving enough moisture, it prevents over-drying of the soil (Edwards and Arancon, 2004). Extensive research has been conducted on amendments to improve plant growth and increase yield under environmental stress conditions. The application of VC causes both enhanced yield and water consumption efficiency (El-Mageed et al., 2019). Alinejad et al. (2020) found that organic fertilizers, particularly VC, were more effective than nitrogen fertilizers at mitigating water stress effects on the jimsonweed plant.

Usage of VC leads to increased plant yield and improves the yield's quality. Zhang et al. (2011) found that adding VC significantly increased N, P, and K contents in the soil, shoot, and the fruit of watermelon. In addition, VC enhanced soluble protein concentration and lycopene in watermelon and improved its marketability. Other studies have also proved the advantages of VC over other organic fertilizers. According to Yang et al. (2015), using VC instead of chick compost and horse compost increased tomato yield and vitamin C under different irrigation regimes. Wang et al. (2017) observed that although applying chicken compost and VC caused improved plant physiological traits compared with mineral fertilizer, VC had caused the enhanced quality of both the fruit and soil. Moreover, increasing chlorophyll and carbohydrates improve drought stress tolerance of plants due to applying VC (Joshi et al., 2013; Amiri et al., 2017).

Cucumber (*Cucumis sativus* L.) is a vegetable belonging to the Curcurbitaceae family and has significant economic value. Due to its vast consumption as a fresh vegetable or pickles, it is produced under greenhouse conditions throughout the year and regardless of climatic conditions (Liu et al., 2021). According to FAO statistics, the total cucumber production in Iran in 2016 was 1,681,784 t, and its area under cultivation was 72,445 hm^2 (FAOSTAT, 2017). The water demand of cucumber is greater than those of other plants such as cereals (Mao et al., 2003). Thus, enhancing water consumption efficiency in cucumber production leads to considerable water

saving. Although, because of cucumber sensitivity to drought (Mao et al., 2003), taking measures to enhance efficiency only by reducing the water used does not seem suitable. Nevertheless, some previous research (Yang et al., 2015) indicated that applying the amendments could help mitigate drought stress resulting from deficit irrigation or environmental conditions in the plant. Deficit irrigation and VC are two common measures for sustainable production in semi-arid regions. Despite substantial research on irrigation water level and VC on different crops, there is no evidence of their interaction effect on cucumber. This study aims to determine the interactive impact of irrigation water and VC on the fruit yield, quality, and IWUE of cucumbers, and to provide a scientific basis for the effective utilization of VC in greenhouse cucumber production.

2 Material and methods

2.1 Study site

This study was conducted in 2018 and 2019 at the Chah-Nimeh greenhouse complex in the Sistan and Baluchistan provinces, southeastern Iran (30°53′24″N, 61°40′12″E; 480 m a.s.l.). The experiments were conducted in a 12 m×60 m greenhouse. The climate of the study region is hot and dry. Generally, the local climate is arid, mild in winter, and warm in summer. The coldest month is January, with an average minimum temperature of 18℃, and the warmest month is July, with an average maximum temperature of 42℃. The annual precipitation is less than 60 mm (Piri and Naserin, 2020). Due to high potential evapotranspiration in the region (about 3500 mm), the farmers' tendency for changing cultivation method from filed to greenhouse has been increased significantly. The experimental greenhouse's soil was sandy loam. Table 1 shows the monthly climatological data for the investigated site.

Table 1 Average monthly maximum, minimum, mean temperature, relative humidity, and evaporation in two growing seasons

Year and month	Temperature			Relative humidity (%)	Evaporation (mm/d)
	Maximum	Mean	Minimum		
2018–2019					
September	32.6	23.9	15.2	23	11.2
October	31.4	15.4	11.6	29	7.2
November	24.6	10.3	4.7	42	5.5
December	18.4	8.9	1.5	43	4.5
January	16.8	13.5	3.8	53	4.2
February	14.3	11.7	4.6	54	3.8
2019–2020					
September	34.2	24.7	16.3	24	12.6
October	32.6	16.5	12.7	29	8.4
November	26.1	11.3	4.8	43	5.7
December	20.4	9.4	2.4	44	4.9
January	17.7	14.6	4.3	54	4.8
February	15.8	12.5	4.1	53	4.1

2.2 Soil condition and VC preparation

Soil samples were collected from two depths (0–30 and 30–60 cm) to determine the soil physical-chemical properties (Table 2). The Kjeldahl method, Olsen method (Olsen and Sommers, 1982), and standard ammonium acetate (Knudsen et al., 1982) were used to measure the phosphorus, potassium, and total nitrogen concentrations, respectively. The Walkley-Black

method (Nelson and Sommres, 1982) was used to determine the soil's organic content. Using an EC meter and a pH meter, the electrical conductivity and pH of the soil were also determined, respectively. The soil analysis results determined N, P, and K fertilizer demand of cucumber during cultivation season. The required fertilizers were given to all experimental treatments using a drip irrigation system as fertigation in three stages before applying water stress. The other agricultural management measures such as pest and weed control were applied similarly for all treatments. Moreover, the final amount of soil salinity has been measured to further investigate the effect of utilization of VC on the soil, and crop yield and characteristics.

Table 2 Soil physical and chemical characteristics

Year	Soil texture	pH	EC (dS/m)	Organic carbon (%)	Total nitrogen (%)	Available potassium (mg/kg)	Available phosphorus (mg/kg)
2018–2019	Loam sand	7.1	0.65	2.6	0.98	314	25.4
2019–2020	Loam sand	6.9	0.71	2.4	1.10	298	28.2

Note: EC, Electrical conductivity.

VC used in this research was prepared from cow manure and matured for three months (Jouquet et al., 2010). The obtained compost was air-dried for one week and passed through a 1-cm sieve. To prepare VC, we used *Eisenia foetida* earthworm. Also, a 5-cm separator layer was placed between the treatments to prevent the effect and transfer of earthworms. VC was added to the soil 10 d before cucumber cultivation, mixed with soil, and eventually bedding occurred. Some physical and chemical properties of VC in the two years of culture are provided in Table 3.

Table 3 Physical and chemical characteristics of applied vermicompost

Year	Organic carbon (%)	Total nitrogen (%)	Total phosphorus (%)	Total sodium (%)	Total calcium (%)	Total potassium (%)	Copper (mg/kg)	Zinc (mg/kg)	Manganese (mg/kg)	Iron (mg/kg)
2018–2019	30.26	3.45	0.34	0.54	3.9	1.1	25	289	84.6	2015
2019–2020	29.31	3.24	0.29	0.58	4.1	1.3	27	276	82.3	2018

2.3 Experimental design

The experiment was set up as a split-plot design with three replications to evaluate how VC affected greenhouse cucumber at varying water levels. The treatments included three VC levels (V_1, V_2, and V_3 corresponding to 10, 15, and 20 t/hm^2, respectively) and three water stress levels (I_1, I_2, and I_3 representing 50%, 75%, and 100% of the plant's water requirement, respectively). Initially, each plot was divided into equal-sized subplots (2 m×3 m), with each subplot separated by a 1-m buffer zone of non-irrigated land. In each of the subplots, three soil beds were created with 1-m intervals. Each subplot consisted of three soil beds (2.0 m long and 0.4 m in width). VC was added to each plot at three mentioned levels before cultivation. Next, in both years, on 25 September, cucumber seeds (*Sina cultivar*) were planted in 3 cm soil depth with 30-cm intervals on the beds. By applying the drip irrigation method, each row of cucumber is irrigated using a polyethylene pipe with a diameter of 16 cm. The emitters were spaced at a 30-cm interval with an irrigation rate of 4 L/(h·m^2). The amount of applied irrigation water was measured by the installed flow meters connected to each water supply pipe. All plots were irrigated until the cucumber plants became four-leaved. Next, water stress treatments were applied. Generally, attempts were made to maintain soil moisture near the field capacity. We determined the levels of applied VC based on the experience of local farmers in greenhouse cultivations of vegetables.

2.4 Determining the plant's water requirement and IWUE

The reference evapotranspiration (ET_0) was calculated using the FAO Penman-Monteith equation (Eq. 1) to determine the volume of water required for irrigation (Allen et al., 1998).

$$\mathrm{ET}_0=\frac{0.408\Delta\left(R_n-G\right)+\gamma\dfrac{C_n}{T+278}U_2\left(e_s-e_a\right)}{\Delta+\gamma\left(1+C_dU_2\right)}, \tag{1}$$

where ET_0 is the reference evapotranspiration (mm/d); R_n is the net input radiation to the plant surface (MJ/(m^2•d)); G is the soil heat flux (MJ/(m^2•d)); T is the mean daily air temperature (°C); U_2 is the mean daily wind speed at altitude of 2 m above sea level (m/s); e_s is the saturation vapor pressure (kPa), e_a is the thereal vapor pressure (kPa); e_s–e_a is the saturation vapor pressure deficit (kPa); Δ is the slope of the saturation vapor pressure curve (kPa/°C); γ is the psychrometric coefficient (kPa/°C); C_n is the coefficient for the reference plant whose value is 900 (kg/(K•kJ•d)); C_d is the wind coefficient for the reference plant, whose value is 0.34 (m/s). The weather data was received from Zahak Agricultural Research Center, which is located next to the greenhouse. The amount of applied irrigation water was calculated using the following equation:

$$V=\frac{I\times S\times K_{r\times}K_c\times\mathrm{ET}_0}{E_a}, \tag{2}$$

where V is the volume of irrigation water volume (m^3); I and S are the length and width of the plot (m); K_c is the crop factor; ET_0 is the reference evapotranspiration (mm); and E_a is the system efficiency that was considered as 90% for the drip irrigation system. Using the FAO instructions and related graph, the coefficient of plant variation (K_c) was determined during the growth season (Allen et al., 1998). The shadow factor is K_r that depends on the ratio of vegetation area to the total area of the field. K_r was calculated using the following equation (Karmeli and Keller, 1975):

$$K_r=\frac{G_s}{0.85}\ \text{or}\ 1, \tag{3}$$

where G_s is the canopy coefficient that was equivalent to the lowest value between 1 and G_s/0.85.

As the reference evapotranspiration in the greenhouse is 60%–80% of its evapotranspiration outside the greenhouse (Rouphael and Colla, 2005), the reference evapotranspiration obtained was multiplied by a factor of 0.7. The water volume of I_1 and I_2 treatments was determined accordingly. IWUE is the crop yield ratio to irrigation water, and is calculated using the following equation (Payero, 2009).

$$\mathrm{IWUE}=\frac{Y}{\mathrm{IR}}\times 100, \tag{4}$$

where IWUE is the irrigation water use efficacy (kg/m^3); Y is the amount of harvested yield (kg/hm^2); and IR is the amount of irrigation water (m^3/hm^2).

2.5 Plant sampling

The first harvest within the first year was performed after 50 d of the seeding date (15 November) and continued until 10 February. The first harvest was done 54 d after the seeding date (19 November) and continued until 10 February in the second year. In each treatment, 10 plants were chosen randomly. Harvest was done once every 4 d. The plant height, weight of fruits, diameter, and length of cucumber in each plot were measured carefully. Carbohydrates, vitamin C, protein content, and chlorophyll *a* and *b* were assessed as quality indicators. Carbohydrates were measured using the method described by Irigoyen et al. (1992), chlorophyll content using the method described by Arnon (1949), and vitamin C using the indophenol titration method (Ting and Rouseff, 1986). Using the method of Justes et al. (1997), the total N content was analyzed to measure the protein content. Next, the acquired value was multiplied by 6.25 to determine the protein content (Connor et al., 2011).

2.6 Statistical analyses

SAS software was utilized for variance analysis of the results acquired from various treatments. The Duncan test was used to compare the mean direct and interaction effects at the 1% and 5% probability levels.

3 Results

Variance analysis of the investigated characteristics is shown in Table 4. Also, Table 5 compares the mean properties using the Duncan test. The results are reported in terms of yield, yield components, IWUE, and quality characteristics in this table. The irrigation water and VC level significantly affected the yield, its components, IWUE, and various quality features. Furthermore, due to the uniformity of environmental conditions in the greenhouse, the cultivation year had no significant impact on any of the analyzed parameter averages (Tables 4 and 5). Therefore, the average of the indices will be used hereafter. Moreover, the amounts of soil salinity of different treatments at the end of the experiment have been presented in Figure 1. The results showed that irrigation, VC, and their interaction significantly affected soil salinity. Soil salinity increased by applying more VC and decreased by increasing irrigation. The highest value of EC (3.18 dS/m) was recorded in I_1V_3 treatment, which received the most amount of VC and the least amount of water. The lowest value of it (1.5 dS/m) was attained in I_3V_1 treatment, which received the most water and the lowest amount of VC.

Table 4 Analysis of variance of the effect of quantity of irrigation water and vermicompost on the studied traits of cucumber and IWUE in two growing seasons

Sources of variation	*df*	Fruit weight (g)	Fruit diameter (cm)	Fruit length (cm)	Plant height (cm)	Cucumber yield (t/hm^2)	IWUE (kg/(m^3•hm^2))	Chlorophyll *a* (mg/g)	Chlorophyll *b* (mg/g)	Vitamin C (mg/100g)	Carbohydrates (mg/g)	Protein (%)
Year (Y)	1	231.41	5.340	1.160	18.95	1.36	1.83	0.19	0.08	0.39	0.27	0.38
Replication (R)	2	2307.33	0.018	0.073	282.15	2.55	2.29	0.12	0.18	0.43	0.64	0.05
Irrigation water (I)	2	3364.06*	2.180**	253.480**	10263.28*	21,812.00**	491.09**	1.23**	1.90**	163.36**	16.19**	32.61*
Y×I	4	23,048.85	0.033	0.160	319.55	0.24	1.31	0.19	0.08	0.95	1.23	1.67
Vermicompost (V)	2	26,984.30*	0.800**	31.120**	2668.69*	3136.00**	105.66**	3.15**	2.62**	245.18**	34.15**	72.14*
Y×V	2	145.03	2.120	4.230	21.15	1.67	2.06	113.03	3.50	3.33	26.23	2.17
I×V	4	21,393.48*	1.570*	24.920**	2351.85*	1763.56**	60.29**	2.07*	2.08*	31.64*	7.21**	2.52*
I×V×Y	4	1563.50	1.150	4.360	7.74	3.56	3.08	263.42	2.58	4.12	7.84	3.42
R×V×I	12	20,120.01	0.008	0.075	371.56	1.22	1.13	0.08	0.16	1.16	1.32	2.48
CV (%)		10.10	4.250	2.040	11.96	2.70	3.59	5.23	4.50	6.35	3.54	6.67
SD		14.60	0.150	0.300	18.50	3.70	1.10	0.02	0.01	0.24	0.01	3.30

Note: * and ** are significant at the 5% and 1% probability levels, respectively.

3.1 Effects of irrigation water and VC on the cucumber yield and yield compositions

The findings revealed that irrigation water level significantly influences cucumber yield and yield components in both years (Table 4). As a result, cucumber yield increased by increasing irrigation water. The highest yield was recorded in I_3 treatment, which received 100% of the plant's water requirement, and the lowest yield was observed in I_1 treatment, which received 50% of I_3 in both years. It is noted that there was no significant difference in the yield between I_2 and I_3 treatments. The level of irrigation water affects fruit weight and plant height at the 5% probability level, and the length and diameter of fruit at the 1% probability level in both years (Table 4). Cucumber's weight, length, diameter, and plant height increased by increasing irrigation water level. Fruit length and weight of I_2 and I_3 treatments were not significantly different. However, fruit diameter and plant height were significantly different. The smallest fruit weight (118 g) was found in I_1 treatment, while the biggest fruit weight (167 g) was found in I_3 treatment (Table 5).

Table 5 Comparison of yield, yield components, quality traits, and IWUE of cucumber in two growing seasons

Treatment	Fruit weight (g)		Fruit diameter (cm)		Fruit length (cm)		Plant height (cm)		Cucumber yield (t/hm^2)		IWUE (kg/(m^3•hm^2))	
	2018–2019	2019–2020	2018–2019	2019–2020	2018–2019	2019–2020	2018–2019	2019–2020	2018–2019	2019–2020	2018–2019	2019–2020
I_3	167.9^{a}	166.3^{a}	3.8^{a}	3.6^{a}	16.9^{a}	17.1^{a}	169.5^{a}	168.5^{a}	155.0	156.2^{a}	25.0^{b}	25.6^{b}
I_2	155.1^{a}	156.0^{a}	3.5^{b}	3.6^{b}	14.8^{a}	15.9^{a}	157.0^{b}	156.4^{b}	149.9^{a}	150.1^{a}	31.8^{a}	31.8^{a}
I_1	117.1^{b}	118.2^{b}	3.3^{c}	3.3^{c}	10.9^{b}	11.2^{b}	134.6^{c}	133.3^{c}	101.9^{b}	102.6^{b}	32.9^{a}	32.9^{a}
V_3	169.8^{a}	168.2^{a}	3.7^{a}	3.6^{a}	14.9^{a}	15.6^{a}	167.1^{a}	166.5^{a}	141.4^{a}	141.9^{a}	31.1^{a}	31.3^{a}
V_2	146.7^{ab}	145.3^{ab}	3.6^{a}	3.5^{a}	14.8^{a}	15.6^{a}	156.8^{ab}	155.4^{ab}	140.5^{a}	140.1^{a}	30.9^{a}	31.1^{a}
V_1	123.5^{b}	124.4^{b}	3.3^{b}	3.2^{b}	13.0^{b}	13.2^{b}	147.3^{b}	146.6^{b}	121.9^{b}	122.3^{b}	27.6^{b}	27.9^{b}

Treatment	Chlorophyll *a* (mg/g)		Chlorophyll *b* (mg/g)		Vitamin C (mg/100g)		Carbohydrates (mg/g)		Protein (%)	
	2018–2019	2019–20	2018–2019	2019–2020	2018–2019	2019–2020	2018–2019	2019–2020	2018–2019	2019–2020
I_3	0.45^{a}	0.47^{a}	0.21^{a}	0.22^{a}	3.22^{b}	3.26^{b}	0.28^{ab}	0.26^{ab}	48.2^{b}	48.6^{b}
I_2	0.38^{a}	0.39^{a}	0.17^{a}	0.17^{a}	3.92^{a}	3.85^{a}	0.36^{a}	0.37^{a}	52.3^{a}	52.5^{a}
I_1	0.26^{b}	0.27^{b}	0.12^{c}	0.12^{c}	4.19^{a}	4.21^{a}	0.20^{b}	0.23^{b}	45.7^{c}	45.2^{c}
V_3	0.43^{a}	0.44^{a}	0.23^{a}	0.24^{a}	4.16^{a}	4.15^{a}	0.32^{a}	0.32^{a}	55.3^{a}	54.9^{a}
V_2	0.37^{ab}	0.38^{ab}	0.19^{ab}	0.20^{ab}	3.95^{a}	3.87^{a}	0.28^{ab}	0.30^{a}	50.6^{ab}	50.8^{ab}
V_1	0.25^{b}	0.26^{b}	0.14^{b}	0.15^{b}	3.17^{b}	3.19^{b}	0.19^{b}	0.20^{a}	45.7^{c}	45.2^{c}

Note: value within each column and for each treatment followed by the same lowercase letters are not significantly different at the 5% probability level.

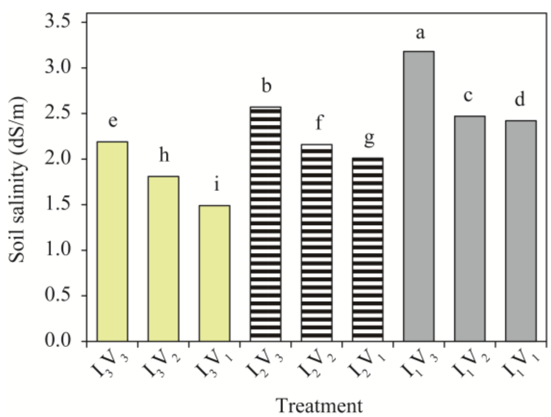

Fig. 1 Interactive effect of irrigation water amounts and VC (vermicompost) levels on soil salinity. Treatment followed by the same lowercase letters are not significantly different at the 5% probability level. V_1, V_2, and V_3 are 10, 15, and 20 t/hm^2 VC, respectively. I_1, I_2, and I_3 are 50%, 75%, and 100% of the plant's water requirements, respectively.

The results indicated that the amount of applying VC influenced the yield and yield components of cucumber significantly in both years (Table 4). Generally, the yield increased by increasing VC in different treatments. The maximum yield (141.5 t/hm^2) came from plots that received 20 t/hm^2 of VC, which was 16% higher than plots that received 10 t/hm^2 of VC. Fruit weight and plant height were influenced by VC at the 5% probability level, and the fruit's length and diameter by VC at the 1% probability (Table 4). The aforementioned physiological characteristics of cucumber were increased by increasing the amount of applied VC. However, there was no significant difference between V_2 and V_3 treatments. The smallest fruit weight (124

g) was found in V_1 treatment, while the largest fruit weight (169 g) was found in V_3 treatment. Furthermore, the largest fruit diameter and length were obtained in V_3 treatment, 16% and 13% higher than in V_1 treatment, respectively (Table 5).

The interaction between VC and irrigation water had a significant impact on the yield and yield components of cucumber (Figs. 2 and 3). Any decrease in VC level resulted in yield reduction when the crop was irrigated at 100% of the plant's water requirement (I_3). The maximum yield was achieved by applying 15 t/hm^2 of VC (V_2), when deficit irrigation (75% and 50% of the plant's water requirements) was used. Similar trends continue for the second growing year. While the highest of 175 t/hm^2 was produced in I_3V_3 treatment, the minimal yield of 97 t/hm^2 was obtained in I_1V_1 treatment, which is roughly 55% of the maximum yield (Fig. 2). Moreover, all yield components and plant height were significantly affected by irrigation water and VC in both years (Table 4). Even yet, the highest amount of product components was recorded in I3 treatment. I_3V_3 and I_2V_2 treatments were found to have the biggest length and diameter of cucumber. However, no significant effect was found in the fruit diameter of cucumber between I_2V_2 and I_3V_3 treatments. In addition, the smallest length of fruit was recorded in treatments that received 50% of the plant's water requirement (I_1). In both years, the highest height plants were recorded in I_3V_3 and I_2V_2 treatments. Although, in the mentioned growth index, there was no significant difference between these treatments. However, the smallest heights were attained for treatments that received 50% of the plant's water requirement (I_1V_1) (Fig. 3).

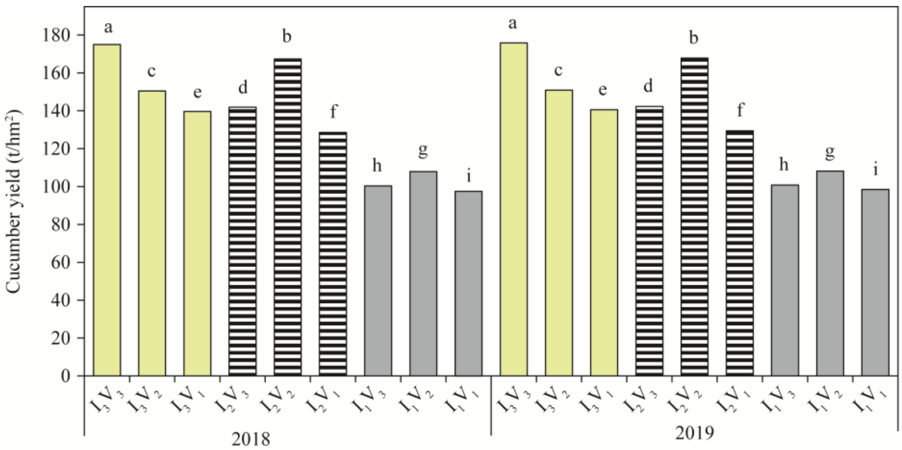

Fig. 2 Interactive effect of irrigation water amounts and VC (vermicompost) levels on cucumber yield in two growing seasons. Treatment followed by the same lowercase letters are not significantly different at the 5% probability level. V_1, V_2, and V_3 are 10, 15, and 20 t/hm^2 VC, respectively. I_1, I_2, and I_3 are 50%, 75%, and 100% of the plant's water requirements, respectively.

3.2 Effects of irrigation water and VC on the cucumber quality characteristics

Results demonstrated that irrigation levels significantly affected chlorophyll *a* and *b*, vitamin C and carbohydrates at the 1% probability level, and protein at the 5% probability levels in both years (Table 4). Chlorophyll *a* and chlorophyll *b*'s contents decreased, and vitamin C increased by reducing the irrigation water amount. In this way, Chlorophyll *a* and *b* increased by 79% and 74% by increasing irrigation water level from I_1 to I_3 treatment. Meanwhile, exposure to water deficiency by 50% of the plant's water requirement increased vitamin C content of fruit by about 30%. Moreover, the highest amounts of carbohydrates and protein were observed in I_2 treatment. Cucumber carbohydrate contents increased from 0.27 to 0.37 mg/g, and protein content increased from 48.4% to 52.4% when the irrigation water level was reduced from I_1 to I_2 treatment

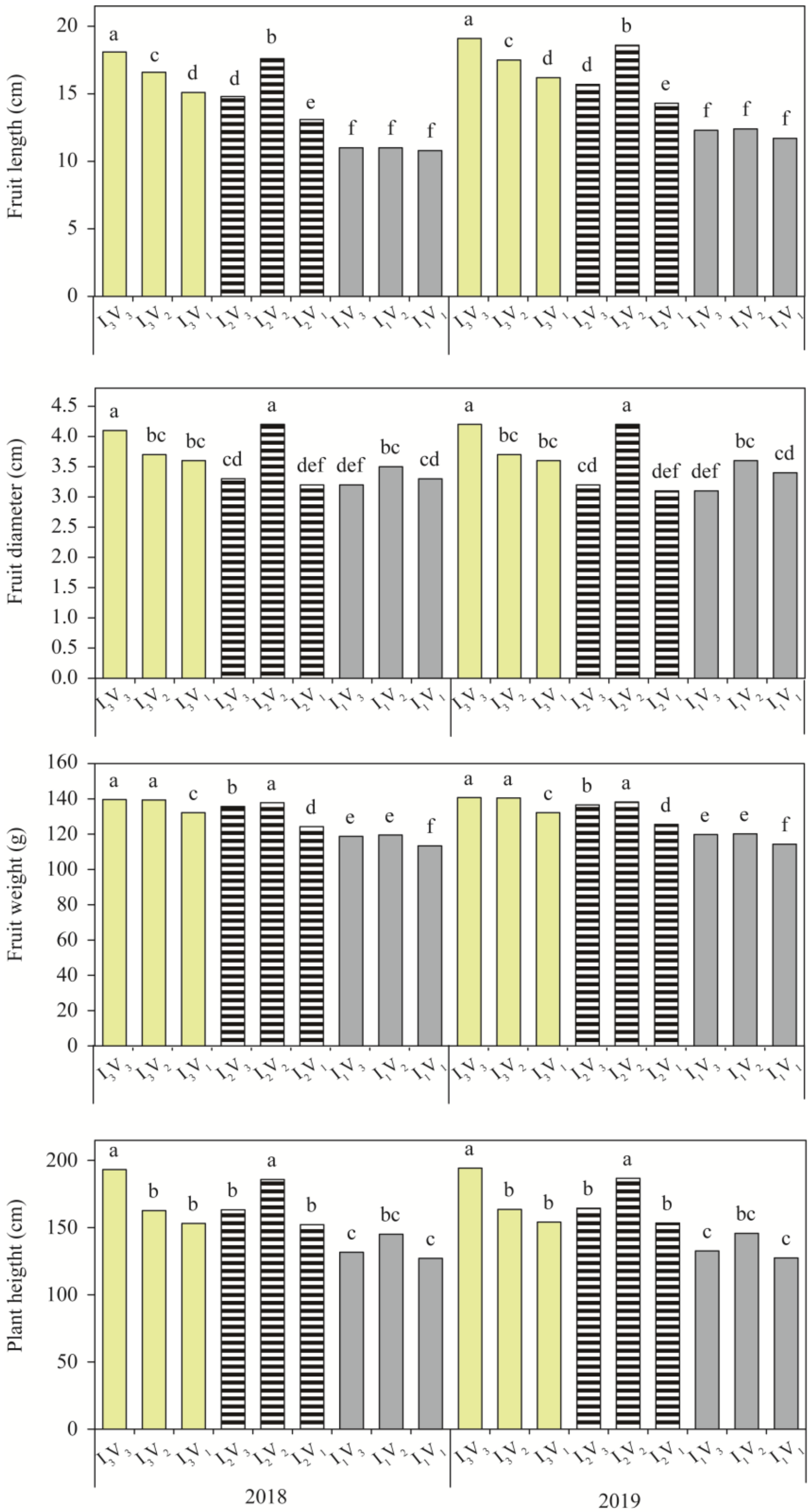

Fig. 3 Interactive effect of irrigation water amount and VC (vermicompost) levels on yield components of cucumber in two growing seasons. Treatment followed by the same lowercase letters are not significantly different at the 5% probability level. V_1, V_2, and V_3 are 10, 15, and 20 t/hm^2 VC, respectively. I_1, I_2, and I_3 are 50%, 75%, and 100% of the plant's water requirements, respectively. (a), fruit length; (b), fruit diameter; (c), fruit weight; (d), plant height.

(Table 5). Analysis results of the experiments of both years showed that applied VC significantly affected all of the studied quality traits of cucumber (Table 4). However, no noticeable difference was found between V_2 and V_3 treatments in all mentioned characteristics. In both years, chlorophyll *a* and *b* contents were increased more than 70% and 62% by increasing VC from 10 to 20 t/hm^2. Moreover, among the other characteristics, carbohydrates were affected by adding VC. Increasing VC from 10 to 20 t/hm^2 increased vitamin C, carbohydrates, and protein contents more than 31%, 64%, and 21%, respectively (Table 5).

Interaction between irrigation water and VC level influenced all measured cucumber quality characteristics (Table 4). The highest chlorophyll *a* and *b* were found in I_3V_3 treatment, i.e., 0.39 and 0.23 mg/g, respectively. In the meanwhile, there was no significant difference between I_3V_3 and I_2V_2 treatments. In I_1V_1 treatment, the chlorophyll *a* and *b* concentrations were 0.15 and 0.10 mg/g, respectively (Fig. 4). The highest vitamin C content (4.08 g/100g) of cucumber was obtained in I_1V_3 treatment, which was 80% higher than that in I_3V_1 treatment with the lowest vitamin C content. However, there was no significant difference between I_1V_3 and I_2V_2 treatments. Moreover, the largest concentrations of carbohydrates and protein were found in I_2V_3 treatment, while the lowest concentrations were found in I_1V_1 treatment. The highest and lowest ratios of carbohydrates and protein concentrations were 2.4 and 2.6, respectively (Fig. 4).

3.3 Effects of irrigation water and VC on the cucumber IWUE

Irrigation water and VC had a significant effect on IWUE in both years. Contrary to the yield trend, IWUE decreased by increasing the irrigation amount. In both years, the highest IWUE achieved in I_1 treatment, which was higher by 3.5% and 30% than those in I_2 and I_3 treatments, respectively (Table 5). Also, IWUE rose by increasing the amount of applied VC to the plots. Increasing VC application rate from 10 to 20 t/hm^2 enhanced IWUE by 12.5% (Table 5). Irrigation water amounts and VC exerted significant interaction effects on IWUE. I_3V_1 treatment had the least IWUE (19.9 kg/(m^3·hm^2)) in both years. The maximum IWUE occurred in I_1V_2 treatment with 35.8 kg/(m^3·hm^2). Even though there was no significant difference between I_1V_2, I_2V_2, and I_2V_3 treatments. In treatments that received the total amount of water required by the plants, IWUE was driven by increasing VC levels. Under deficit irrigation conditions, however, the maximum IWUE was achieved using 15 t/hm^2 of VC. In addition, when 10 t/hm^2 of VC was applied, increasing irrigation water decreased IWUE. However, the maximum IWUE was obtained when the plants received 75% of their required water (Fig. 5).

4 Discussion

4.1 Cucumber yield, irrigation water and soil salinity

Yields across different treatments ranged from 97.9 to 175 t/hm^2 in both years. These values vary in different studies due to meteorological conditions, soil, water quality, and irrigation method, as well as the growing system. The maximum yield was close to the values obtained in the research by Soleimani et al. (2009) with 130–150 t/hm^2 and Çakir et al. (2017) with 130–140 t/hm^2. Nevertheless, Grewal et al. (2011) reported 204 t/hm^2 in hydroponic cultivation of mini cucumber. Because of similar climate conditions in experimental seasons (Table 1), irrigation water requirement was close to each other. The average irrigation water in two consecutive years was 654 and 642 mm, respectively. Accordingly, the mentioned values had been applied to plots that were irrigated fully. Also, the other scenarios had received water about 50% and 75% of the control treatments.

The raw materials used for VC production and the release of nutrients affect the EC (Atiyeh et al., 2002; Gonzalez et al., 2010). The EC of VC in this study was relatively high, affecting the soil EC. Because of the low EC of water, increasing soil salinity is dependent on the salinity level of VC. In addition, applying water as a means of leaching reduces the VC-induced salinity. Since the final value of EC was higher than the threshold of 4 dS/m, it should be applied to the VC in the field carefully.

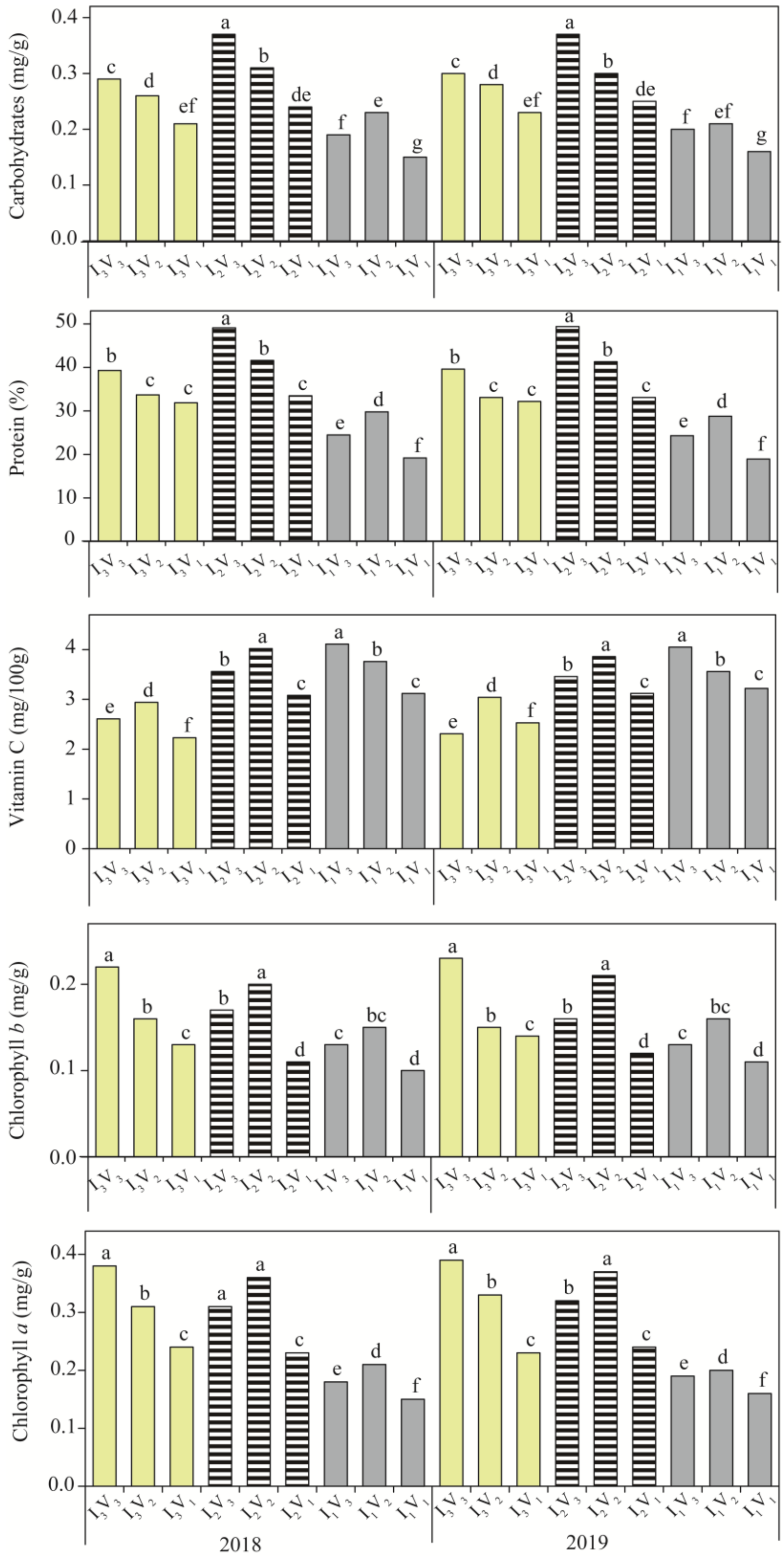

Fig. 4 Interactive effects of irrigation water amount and VC (vermicompost) levels on quality traits of cucumber in two growing seasons. Treatment followed by the same lowercase letters are not significantly different at the 5% probability level. V_1, V_2, and V_3 are 10, 15, and 20 t/hm^2 VC, respectively. I_1, I_2, and I_3 are 50%, 75%, and 100% of the plant's water requirements, respectively. (a), carbohydrates; (b), protein; (c), vitamin C; (d), chlorophyll *b*; (e), chlorophyll *a*.

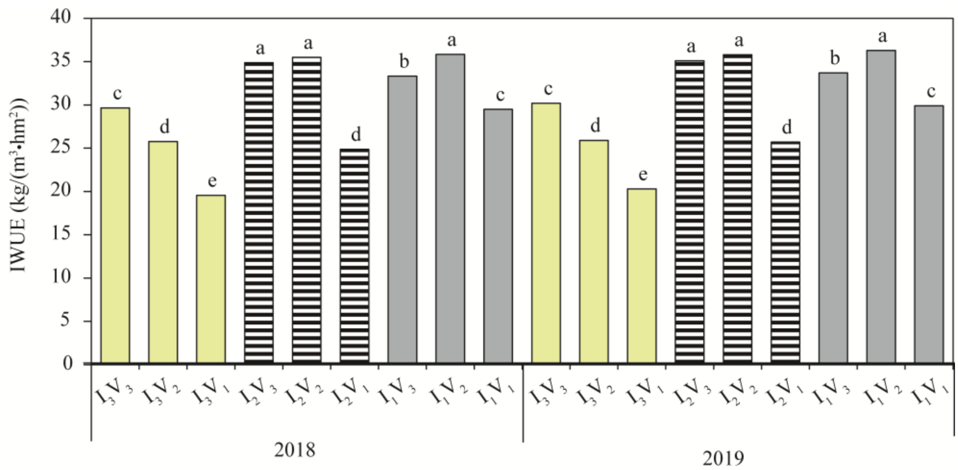

Fig. 5 Interactive effect of irrigation water amounts and VC (vermicompost) levels on IWUE (irrigation water use efficiency) in two growing seasons. Treatment followed by the same lowercase letters are not significantly different at the 5% probability level. V_1, V_2, and V_3 are 10, 15, and 20 t/hm^2 VC, respectively. I_1, I_2, and I_3 are 50%, 75%, and 100% of the plant's water requirements, respectively.

4.2 Effects of irrigation water and VC on the cucumber yield and yield compositions

Since cucumber requires adequate water across all stages of its development (Mao et al., 2003), the yield and its components have diminished under the water deficit condition (Table 5). This decreased yield was not statistically significant between l2 and l3 treatments. On the other hand, the application of 50% of the required water resulted in more than one-third of reduction in the cucumber yield (Table 5). The decline in the available water would reduce the water potential, thus retarding the cucumber growth. Although fruits are stronger sinks than green parts of the plant (Chalmers, 1989), yield reduction becomes unavoidable if further water deficit occurs. Other researchers (El-Mageed and Semida, 2015; Çakir et al., 2017) have reported similar results, i.e., an upward tendency of yield with an increase in water. Irrigation influenced the length, diameter, and weight of cucumber fruit (Wang et al., 2009). Under water shortage conditions, a reduction in growth hormone secretion and an increase in growth inhibitor compounds are two of the most common causes of stunted aerial development (Bayoumi et al., 2008). El-Mageed et al. (2018) concluded that the maximum fruit weight was obtained in treatments with full irrigation.

Similar to our findings, Zhao et al. (2017) concluded that adding VC enhanced cucumber yield. However, ambiguity remains about the beneficial value of VC, since beyond it, VC application can harm the growth of plants (Hussain and Abbasi, 2018). Azarmi et al. (2009) reported no difference between treatments receiving 20 and 30 t/hm^2 of VC in cucumber yield. Therefore, uncertainty exists about the proper levels of application of VC for different stages of growth and various plants. Nevertheless, similar to yield, some of the soil characteristics only improve to a certain level by adding VC, beyond which it can affect negatively (Aksakal et al., 2016). As a result, despite the advantages, over-usage of VC inhibits plant growth due to the excessive nutrient contents in relation to the plant needs (Hussain et al., 2015), increased soil salinity, especially in the primary stages of the plant development (Atiyeh et al., 2001b), as well as abundance of materials with a humic (Atiyeh et al., 2001a) and phenolic (Ievinsh, 2011) nature in the root environment. The results revealed a descending trend in the weight, diameter, and length of fruit upon VC reduction. It can be attributed to improved essential growth supplies such as photosynthesis, energy storage, and cell development (Yadav et al, 2017). Adding VC to the soil increased root nodule formation and colonization by arbuscular mycorrhizal fungi and led to a higher increase in the humic acid-rich VC (Maji et al., 2017). Furthermore, an increase in VC had a boosting effect on the plant height (Table 5). Kashem et al. (2015) reported that 20 t/hm^2 of VC resulted in increased plant height as well as the number and weight of fruits of tomato. Probably,

the presence of growth regulators such as indole acetic acid in VC is the main reason in plant height elevation (Warman and AngLopez, 2010).

In the treatments with water deficit (I_1 and I_2 levels), the maximum yield was recorded when using 15 t/hm^2 VC, while at higher and lower levels of VC, lower yields were obtained (Fig. 2). Although use of VC can mitigate the adverse effects of water stress in plants by increasing calcium and potassium absorption while reducing sodium absorption (Hosseinzadeh et al., 2017), a rise in VC, beyond a certain level, leads to increased salinity in the root environment. In this condition, applying deficit irrigation causes inadequate salt leaching and diminished yield. In the present study, in general, this optimum level was 15 t/hm^2 under the water deficit condition. The fruit's weight, diameter, and length dropped under complete irrigation circumstances when VC concentration was reduced. However, at lower levels of irrigation, with a reduction of VC level from 20 to 15 t/hm^2, the weight, diameter, and length of fruit increased, and its further reduction resulted in a decline in the value of the indices. Generally, it seems that VC content must be reduced to apply deficit irrigation appropriately. High amounts of VC, by enhancing soil salinity, may harm the plant development and cause reduced diameter as well as length of fruit (Atiyeh et al., 2001a; Demir, 2019). Similarly, Li et al. (2010) reported that the combination of VC and irrigation influenced plant height. Generally, existence of different salts in VC result in increased salinity and water reduction due to deficit irrigation, which can intensify the saltiness. In this condition, applying VC by providing adequate water can stimulate the growth of aerial parts of the plant (Li et al., 2010).

4.3 Effects of irrigation water and VC on the cucumber quality characteristics

In chlorophyll *a* and *b*, there was a downward trend. The chlorophyll content in the leaves influences the rate of photosynthesis and the quantity of dry mass produced by the plant (Ghosh et al., 2004). As a result, the reduction in chlorophyll concentration under drought stress might be regarded as a non-stomatal limiting factor in photosynthesis (Hoekstra et al., 2001). The components required for chlorophyll synthesis diminish as water deficit stress increases, but its degradation also increases. As a result, chlorophyll biosynthesis is restricted. Manivaannan et al. (2007) observed that deficit irrigation lowered the concentrations of chlorophyll *a* and *b* in sunflower compared with the control chlorophyll. However, Xu and Leskovar (2014) reported the highest chlorophyll content under average stress conditions.

In other previous studies (Liu et al., 2019), deficit irrigation heightened vitamin C levels. This elevation is due to a heightened sugar concentration in the fruit as a precursor of vitamin C synthesis (Liu et al., 2019). Also, Wang et al. (2011) attributed diminished vitamin C levels to decreased light intake because of the leaf's reduced ability arising from water deficits. Meanwhile, carbohydrates are signaling molecules. Drought stress increases soluble sugar concentrations by digesting and reducing starch in response to increased amylase enzyme activity, resulting in a high concentration of carbohydrates (Anderson and Kohorn, 2001). The increase in carbohydrates prevents protein breakdown and thus preserves the turgescence of leaf cells as well as cell membranes. It also prevents the plant's mortality by providing the required energy (Xue et al., 2008). In treatments with a water deficit, reducing the number of fruits (yield) may increase the amount of water and carbohydrates in the remaining fruits (Dorji et al., 2005). As a result, synthesis and abundance of other biochemical parameters should logically follow the same pattern. Although some research, such as Pelah et al. (1997), has indicated that water stress increases protein content, severe water stress lowers protein production dependent on adequate water. Similar to the present study's findings, Afshar et al. (2014) found that mild water stress increases the protein content of milk thistle. It can be interpreted by this fact that with the increase in irrigation amount, the condition for nitrogen leaching in the soil is further provided. Thus, nitrogen uptake by the plant is reduced, and the concentration of protein in cucumber is diminished.

Generally, fruit quality is promoted by VC elevation (Table 5). Previous studies reported that

applying VC improves the overall quality of cucumbers under greenhouse conditions (Zhao et al., 2010, 2017). The effects of VC in increasing chlorophyll are possible because of the affirmative impact of VC in enhancing the physical-chemical properties of soil, boosting access to water and nutrients, as well as the presence of active biological materials resulting from the interactions of microorganisms as well as earthworms (during VC processing), such as plant hormones in VC (Fritz et al., 2012). Nevertheless, in addition to its direct role in feeding the plant, VC contributes to greater absorption of nutrients by developing a root system (Hussain et al., 2018). Possibly, increased access to nutrients results in an elevated level of pigments and photosynthesis, thereby enhancing carbon fixation and the development of the plant as well as yield.

Unlike nitrogen fertilizer that allows adding vitamin C up to a certain level (Wang et al., 2019), in this research, no specific limit was found for increasing vitamin C that results from the addition of VC. Nevertheless, Yang et al. (2015) reported a minor positive effect of VC on vitamin C in tomatoes. In some research, such as Wang et al. (2010), a 5.8-fold difference was reported for vitamin C of Chinese cabbage between optimal VC and control treatments. Although some previous research, the addition of VC greatly boosted the carbohydrate content in wheat (Joshi et al., 2013) and tomato (Gutiérrez-Miceli et al., 2007). In this study, there was no significant difference in the carbohydrate content of cucumber across treatments. In another study, Javed and Panwar (2013) showed that VC enhanced the accumulation of carbohydrates in soybeans more than biofertilizers. Release of nitrogenated compounds from VC during the growing season and supplying considerable amounts of the prerequisite elements for protein production from VC fertilizer resulted in enhanced plant protein content (Muhammad and Hussain, 2010). Previous studies have also reported a rise in the plant's protein content in conjunction with higher levels of absorbable nitrogen (Glenn, 1985). Similar to the current study's findings, Xu and Mou (2016) as well as Kumar Srivastava et al. (2011) found that VC increased protein content in spinach and mustard, respectively.

I_3V_3 treatment yielded the highest chlorophyll *a* and *b*, though this was not significantly different from I_2V_2 treatment (Fig. 4). As such, it may be stated that the amount of VC applied should be lowered when water stress levels are high. The elevation of chlorophyll in response to the application of VC may be due to its impact on improving the soil humidity balance and its influence on elevating the soil's available nitrogen (Chaves et al., 2002). Salehi et al. (2016) found that adding VC led to elevated chlorophyll *b* of the German chamomile plant under conditions of no water stress or low water stress. However, if stress becomes more severe, adding VC would cause diminished chlorophyll in this plant.

The increases in fruit quality indices, such as carbohydrates and vitamin C, are due to high amounts of humic acids, nutrients, and plant physiologically active substances in VC. Their effectiveness depends on the existence of optimum amount of soil water. Vitamin C concentrations were elevated as irrigation water levels decreased, and VC content increased, according to the interaction between these two factors (Fig. 4). Yang et al. (2015) found that the maximum impact of VC in increasing vitamin C would occur under mild stress (60%–70% of field capacity) compared with chemical fertilizer, chicken compost, and horse compost. Favati et al. (2009) and Liu et al. (2019) examined tomatoes and found a correlation between high concentrations of vitamin C and low yield. Furthermore, larger fruits have less vitamin C, and such correlations exist in this study. The results indicated that the carbohydrate content increased by reducing irrigation water by up to 75% of the plant's water requirement and elevating VC level. Possibly, upon supplying plants with essential elements and enough water, VC promotes the development, accelerates metabolism reactions, and augments the synthesis and aggregation of metabolites, including carbohydrates. Accumulating soluble sugars as osmotic regulators is one of the adaptive responses of plant against water deficit stress to maintain osmotic balance. Over-aggregation of soluble sugars at the time of stress can be due to the degradation of non-soluble sugars and stopped growth or synthesis of these compounds from non-photosynthetic pathways (Shabala and Munns, 2017). In examining the interaction effects of water and VC on

cucumber, a similar trend was observed in the protein content of fruits. According to the results, adding VC under mild stress conditions significantly boosted the protein content. The enhanced biological activity in the growth medium containing VC and enough moisture would improve the uptake of elements such as nitrogen, causing enhanced plant yield and protein content (Zaller, 2007). Wei et al. (2009) found that the maximum soluble protein content in tomatoes was achieved when using average irrigation levels and maximizing fertilizer use.

4.4 Effects of irrigation water and VC on the cucumber IWUE

IWUE calculated in this study was relatively lower than other similar research such as Çakir et al. (2017) and in agreement with the results of Ayas and Demirtas (2009). The difference in amounts of IWUE may result from the marketable size of cucumber. In the Iranian market, the smaller size of cucumber is more pleasant. Thus, farmers prefer to harvest fruits before reaching their final size. Previous studies have mostly reported that applying less water would enhance IWUE (El-Mageed et al., 2018). On the other hand, in the regions that economic value of water is significantly high, less water utilization is crucial. Accordingly, it is true that saving 50% of the cucumber water requirement is preferred. However, since the higher amount and quality of cucumber is more valuable economically, utilization of 25% of the irrigation water may be preferable. These results were in line with the findings of El-Mageed et al. (2018).

The reduction of VC consumption led to decreased IWUE. By constructing a proper structure, VC promotes plant root growth and development as a water source. Furthermore, VC reduces deep percolation and runoff by boosting the soil's water-holding capacity. Thus, it makes the water more accessible for the plants and promotes IWUE. Xu and Mou (2016) investigated the effect of VC on spinach and concluded that VC positively impacts WUE of spinach. This resulted from adding more nutrients and improvements to the soil's physical properties such as water holding capacity. The results indicated that changes of IWUE had a similar trend with yield in the face of the interaction of VC and irrigation water. The maximum IWUE was observed under 20 t/hm^2 VC and full irrigation treatments. There is a fact that the addition of VC improves soil conditions and then enhances the chance of exchange with roots cells (Asli and Neumann, 2010). In the present study, it was expected that the elevation of VC would lead to diminished IWUE because of decreased yield (Fig. 5). In I_3 treatment, irrigation by enough water supplied the leaching water requirement. Indeed, VC-induced soil salinity is affected as a hidden diminishing factor of IWUE. Similarly, Nazarideljou and Heidari (2014) stated that at all three irrigation levels, the maximum WUE was obtained at average values of VC (2.5% of the total weight). Furthermore, according to Khosravi-Shakib et al. (2019), addition of VC by 30% in 40% available water capacity (AWC) treatment resulted in an increase in WUE of marigold by up to four times as large as that of control treatment.

5 Conclusions

Cucumber production, components of yield, quality, and IWUE were all significantly affected by the amount of irrigation water and VC level and their interaction. Using VC had a beneficial effect on cucumber yield, yield components, quality characteristics, and IWUE. However, deficit irrigation decreased the yield, yield components, chlorophyll *a* and *b*, and increased IWUE and vitamin C. The maximum carbohydrate and protein content was recorded in l_2 treatment. Also, the maximum yield and its components were obtained under full irrigation condition. When using 20 t/hm^2, these parameters in these two treatments did not differ significantly with 75% of the plant's water requirement and 15 t/hm^2, respectively. Investigation of the interactive effect of irrigation water and VC showed that only under full irrigation condition, increasing VC amounts resulted in enhanced yield and reduced IWUE. In applying deficit irrigation, increasing VC beyond 15 t/hm^2 would not improve the yield and IWUE. In deficit irrigation, the application of VC is a suitable solution to prevent the reducing cucumber yield and its quality. Nevertheless, salinity level resulting from VC should be within its recommended limits. Moreover, improving soil condition

using VC amendment may need more time than two years to reveal all of its effects.

Acknowledgements

This work was supported by the University of Zabol, Iran (UOZ-GR-1837).

References

Afshar R K, Chaichi M R, Assareh M H, et al. 2014. Interactive effect of deficit irrigation and soil organic amendments on seed yield and flavonolignan production of milk thistle (*Silybum marianum* L. Gaertn.). Industrial Crops and Production, 58: 166–172.

Aksakal E L, Sari S, Angin I. 2016. Effects of vermicompost application on soil aggregation and certain physical properties. Land Degradation and Development, 27(4): 983–995.

Alinejad S, Sarabi V, Bakhtvari A R S, et al. 2020. Variation in physiological traits, yield and secondary metabolites of jimsonweed (*Datura stramonium* L.) under different irrigation regimes and nutrition systems. Industrial Crops and Products, 143: 111916, doi: 10.1016/j.indcrop.2019.111916.

Allen R, Pereira L, Raes D, et al. 1998. Crop evapotranspiration guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper 56. FAO, Rome, Italy.

Amiri H, Ismaili A, Hosseinzadeh S R. 2017. Influence of vermicompost fertilizer and water deficit stress on morpho-physiological features of chickpea (*Cicer arietinum* L. cv. karaj). Compost Science and Utilization, 25(3): 152–163.

Anderson C M, Kohorn B D. 2001. Inactivation of *Arabidopsis SIP1* leads to reduced levels of sugars and drought tolerance. Plant Physiology, 158(9): 1215–1219.

Arnon D I. 1949. Copper enzymes in isolated chloroplasts, polyphenoloxidase in *Beta vulgaris*. Plant Physiology, 24(1): 1–15.

Asli S, Neumann P M. 2010. Rhizosphere humic acid interacts with root cell walls to reduce hydraulic conductivity and plant development. Plant and Soil, 336: 313–322.

Atiyeh R M, Arancon N, Edwards C A, et al. 2001a. The influence of earthworm processed pig manure on the growth and productivity of marigolds. Bioresource Technology, 81(2): 103–108.

Atiyeh R M, Edwards C A, Edwards C, et al. 2001b. Pig manure vermicompost as a component of a horticultural bedding plant medium: Effects on physicochemical properties and plant growth. Bioresource Technology, 78(1): 11–20.

Atiyeh R M, Arancon N, Edwards C A, et al. 2002. The influence of earthworm-processed pig manure on the growth and productivity of marigolds. Bioresource Technology, 81(2): 103–108.

Azarmi R, Giglou M T, Hajieghrari B, et al. 2009. The effect of sheep-manure vermicompost on quantitative and qualitative properties of cucumber (*Cucumis sativus* L.) grown in the greenhouse. African Journal of Biotechnolgy, 8(19): 4953–4957.

Bayoumi T Y, Eid M, Metwali E M, et al. 2008. Application of physiological and biochemical indices as a screening technique for drought tolerance in wheat genotypes. Biotechnology, 7(14): 2341–2352.

Çakir R, Kanburoglu-Çebi U, Altintas S, et al. 2017. Irrigation scheduling and water use efficiency of cucumber grown as a spring-summer cycle crop in solar greenhouse. Agricultural Water Management, 180: 78–87.

Celestina C, Hunt J R, Sale P W, et al. 2019. Attribution of crop yield responses to application of organic amendments: A critical review. Soil and Tillage Research, 186: 135–145.

Chalmers D J. 1989. A physiological examination of regulated deficit irrigation. New Zealand Journal of Agricultural Science, 23: 44–48.

Chaves M M, Pereira J S, Maroco J, et al. 2002. How plants cope with water stress in the field? Photosynthesis and growth. Annals of Botany, 89(7): 907–916.

Connor D J, Loomis R S, Cassman K G. 2011. Crop Ecology: Productivity and Management in Agricultural Systems (2nd ed.). Cambridge: Cambridge University Press, 562.

Demir Z. 2019. Effects of vermicompost on soil physicochemical properties and lettuce (*Lactuca sativa* var. Crispa) yield in greenhouse under different soil water regimes. Communications in Soil Science and Plant Analysis, 50(17): 2151–2168.

Dorji K, Behboudian M H, Zegbe-Dominguez J A, et al. 2005. Water relations, growth, yield, and fruit quality of hot pepper under deficit irrigation and partial root zone drying. Scientia Horticulturae, 104(2): 137–149.

Edwards C A, Arancon N Q, Shelman R L. 2010. Vermiculture Technology: Earthworms, Organic Wastes, and Environmental Management. Boca Raton: CRC Press, 623.

El-Mageed T A A, Semida W M. 2015. Effect of deficit irrigation and growing seasons on plant water status, fruit yield and water use efficiency of squash under saline soil. Scientia Horticulturae, 186: 89–100.

El-Mageed T A A, Semida W M, Taha R S, et al. 2018. Effect of summer-fall deficit irrigation on morpho-physiological,

anatomical responses, fruit yield and water use efficiency of cucumber under salt affected soil. Scientia Horticulturae, 237: 148–155.

El-Mageed T A A, El-Sherif A M. 2019. A novel compost alleviate drought stress for sugar beet production grown in Cd-contaminated saline soil. Agricultural Water Management, 226: 805–831.

FAOSTAT. 2017. Cucumber Production. [2020-11-11]. http://www.fao.org/faostat/en/# data/QC.

Favati F, Lovelli S, Galgano F, et al. 2009. Processing tomato quality as affected by irrigation scheduling. Scientia Horticulturae, 122(4): 562–571.

Fritz J I, Franke-Whittle I H, Haindl S, et al. 2012. Microbiological community analysis of vermicompost tea and its influence on the growth of vegetables and cereals. Canadian Journal of Microbiology, 58(7): 836–847.

Geerts S, Raes D. 2009. Deficit irrigation as an on-farm strategy to maximize crop water productivity in dry areas. Agricultural Water Management, 96(9): 1275–1284.

Ghosh P K, Bandyopadhyay K K, Manna M C, et al. 2004. Comparative effectiveness of cattle manure, poultry manure, phosphocompost and fertilizer-NPK on three cropping systems in vertisols of semi-arid tropics. II. Dry matter yield, nodulation, chlorophyll content and enzyme activity. Bioresourrce Technology, 95(1): 85–93.

Glenn D M, Carey A, Bolton F E, et al. 1985. Effect of N fertilizer on protein content of grain, straw, and chaff tissues in soft white winter wheat. Agronomy Journal, 77(2): 229–232.

Gonzalez M, Gomez E, Comese R, et al. 2010. Influence of organic amendments on soil quality potential indicators in an urban horticultural system. Bioresource Technology, 101(22): 8897–901.

Grewal H S, Maheshwari B, Parks S E, et al. 2011. Water and nutrient use efficiency of a low cost hydroponic greenhouse for a cucumber crop: An Australian case study. Agricultural Water Management, 98(5): 841–846.

Gutiérrez-Miceli F A, Santiago-Borraz J, Molina J A M, et al. 2007. Vermicompost as a soil supplement to improve growth, yield and fruit quality of tomato (*Lycopersicum esculentum*). Bioresource Technology, 98(15): 2781–2786.

Hijbeek R, Pronk A A, van Ittersum M K, et al. 2018. What drives farmers to increase soil organic matter? Insights from the Netherlands. Soil Use and Management, 34(1): 85–100.

Hoekstra F, Golovia A, Buitink J, et al. 2001. Mechanisms of plant desiccation tolerance. Trends in Plant Science, 6(9): 431–438.

Hosseinzadeh S R, Amiri H, Ismaili A, et al. 2017. Nutrition and biochemical responses of chickpea (*Cicer arietinum* L.) to vermicompost fertilizer and water deficit stress. Journal of Plant Nutrition, 40(16): 2259–2268.

Hussain N, Abbasi T, Abbasi S A, et al. 2015. Vermicomposting eliminates the toxicity of lantana (*Lantana camara*) and turns it into a plant friendly organic fertilizer. Journal of Hazardous Materials, 298: 46–57.

Hussain N, Abbasi S A. 2018. Efficacy of the vermicomposts of different organic wastes as "clean" fertilizers: state-of-the-art. Sustainability, 10(4): 1205.

Hussain S, Sharif M, Ahmad W, et al. 2018. Soil and plants nutrient status and wheat growth after mycorrhiza inoculation with and without vermicompost. Journal of Plant Nutrition, 41(12): 1534–1546.

Ievinsh G. 2011. Vermicompost treatment differentially affects seed germination, seedling growth and physiological status of vegetable crop species. Plant Growth Regulation, 65(1): 169–181.

Irigoyen J J, Einerich D W, Sánchez-Díaz M, et al. 1992. Water stress induced changes in concentrations of proline and total soluble sugars in nodulated alfalfa (*Medicago satida*) plants. Physiologia Plantarum, 84(1): 55–60.

Javed S, Panwar A. 2013. Effect of biofertilizer, vermicompost and chemical fertilizer on different biochemical parameters of *Glycine max* and *Vigna mungo*. Recent Research in Science and Technology, 5: 40–44.

Joshi R, Vig A P, Singh J, et al. 2013. Vermicompost as soil supplement to enhance growth, yield and quality of *Triticum aestivum* L.: A field study. International Journal of Recycling of Organic Waste in Agriculture, 2(1): 1–7.

Jouquet P, Plumere T, Thu T D, et al. 2010. The rehabilitation of tropical soils using compost and vermicompost is affected by the presence of endogeic earthworms. Applied Soil Ecology, 46(1): 125–133.

Justes E, Meynard J M, Mary B, et al. 1997. Management of N nutrition: diagnosis using stem base extract: JUBIL method. In: Lemaire G. Diagnosis of the Nitrogen Status in Crops. Berlin: Spinger Verlag, 163–187.

Kashem A, Sarker A, Hossain I, et al. 2015. Comparison of the effect of vermicompost and inorganic fertilizers on vegetative growth and fruit production of tomato (*Solanumly copersicum* L.). Open Journal of Soil Science, 5: 53–65.

Khosravi Shakib A, Rezaei Nejad A, Khandan Mirkohi A, et al. 2019. Vermicompost and manure compost reduce water-deficit stress in pot marigold (*Calendula officinalis* L. cv. Candyman Orange). Compost Science & Utilization, 27(1): 61–68.

Kumar Srivastava P, Singh P C, Gupta M, et al. 2011. Influence of earthworm culture on fertilization potential and biological activities of vermicomposts prepared from different plant wastes. Journal of Plant Nutrition and Soil Science, 174(3): 420–429.

Li S, Xue X, Guo W, et al. 2010. Effects of water and fertilizer coupling on yield and water use efficiency in greenhouse potted cucumber. Plant Nutrition and Fertilizer Science, 16(2): 376–381. (in Chinese)

Liu H, Li H, Ning H, et al. 2019. Optimizing irrigation frequency and amount to balance yield, fruit quality and water use efficiency of greenhouse tomato. Agricultural Water Management, 226: 105787, doi: 10.1016/j.agwat.2019.105787.

Liu H, Yin C, Gao Z, et al. 2021. Evaluation of cucumber yield, economic benefit and water productivity under different soil matric potentials in solar greenhouses in North China. Agricultural Water Management, 243: 106442, doi: 10.1016/j.agwat.2020.106442.

Maji D, Misra P, Singh S, et al. 2017. Humic acid rich vermicompost promotes plant growth by improving microbial community structure of soil as well as root nodulation and mycorrhizal colonization in the roots of *Pisum sativum*. Applied Soil Ecology, 110: 97–108.

Manivaannan P, Abdul Jaleel C, Sanka B, et al. 2007. Growth biochemical modifications and proline metabolism in *Helianthus annuus* L. as induced by drought stress. Colloids and Surfaces B: Biointerfaces, 59(2): 141–149.

Mao X, Liu M, Wang X, et al. 2003. Effects of deficit irrigation on yield and water use of greenhouse grown cucumber in the North China Plain. Agricultural Water Management, 61(3): 219–228.

Meyer-Kohlstock D, Schmitz T, Kraft E, et al. 2015. Organic waste for compost and biochar in the EU: Mobilizing the potential. Resources, 4(3): 457–475.

Muhammad Z, Hussain F. 2010. Effect of NaCl salinity on the germination and seedling growth of some medicinal plants. Pakistan Journal of Botany, 42(2): 889–897.

Nazarideljou M J, Heidari Z. 2014. Effects of vermicompost on growth parameters, water use efficiency and quality of zinnia bedding plants (*Zinnia elegance* 'dreamland red') under different irrigation regimes. International Journal of Horticultural Science and Technology, 1(2): 141–150.

Nelson D W, Sommers L P. 1982. Total carbon, organic carbon and organic matter, In: Page A L, Miller R H, Keeney D R. Methods of Soil Analysis, Part 2–Chemical and Microbiological Properties (2nd ed.). Madison: Soil Science Society of America, 225–246.

Nelson P N, Oades J M. 1998. Organic matter, sodicity, and soil structure. In: Sumner M E, Naidu R. Sodic Soils. New York: Oxford University Press, 51–75.

Olsen S R, Sommers L E. 1982. Phosphorus. In: Page A L, Miller R H, Keeney D R. Methods of Soil Analysis, Part 2–Chemical and Microbiological Properties (2nd ed.). Madison: Soil Science Society of America, 403–430.

Payero J O, Tarkalson D D, Irmak S, et al. 2009. Effect of timing of a deficit-irrigation allocation on corn evapotranspiration, yield, water use efficiency and dry mass. Agricultural Water Management, 96(10): 1387–1397.

Pelah D, Wang W, Altman A, et al. 1997. Differential accumulation of water stress-related proteins, sucrose synthase and soluble sugars in *Populus* species that differ in their water stress response. Physiologia Plantarum, 99(1): 153–159.

Piri H, Naserin A. 2020. Effect of different levels of water, applied nitrogen and irrigation methods on yield, yield components and IWUE of onion. Scientia Horticulturae, 268: 109361, doi: 10.1016/j.scienta.2020.109361.

Piri H, Naserin A. 2022. Comparison of different irrigation methods for onion by means of water and nitrogen response functions. The Journal of Horticultural Science and Biotechnology, 97(1): 122–136.

Rouphael Y, Colla G. 2005. Radiation and water use efficiencies of greenhouse zucchini squash in relation to different climate parameters. European Journal of Agronomy, 23(2): 183–194.

Salehi A, Tasdighi H, Gholamhoseini M, et al. 2016. Evaluation of proline, chlorophyll, soluble sugar content and uptake of nutrients in the German chamomile (*Matricaria chamomilla* L.) under drought stress and organic fertilizer treatments. Asian Pacific Journal of Tropical Biomedicine, 6(10): 886–891.

Shabala S, Munns R. 2017. Salinity stress: physiological constraints and adaptive mechanisms. In: Shabala S. Plant Stress Physiology (2nd ed.). Wallingford: CABI, 24–63.

Soleimani A, Ahmadikhah A, Soleimani S, et al. 2009. Performance of different greenhouse cucumber cultivars (*Cucumis sativus* L.) in southern Iran. African Journal of Biotechnology, 8(17): 4077–4083.

Ting S, Rouseff L. 1986. Citrus Fruits and their Products: Analysis, Technology. New York: Marcel Dekker Inc., 293.

Wang D, Shi Q, Wang X, et al. 2010. Influence of cow manure vermicompost on the growth, metabolite contents, and antioxidant activities of Chinese cabbage (*Brassica campestris* ssp. chinensis). Biology and Fertility of Soils, 46(7): 689–696.

Wang F, Kang S, Du T, et al. 2011. Determination of comprehensive quality index for tomato and its response to different irrigation treatments. Agricultural Water Management, 98(8): 1228–1238.

Wang H, Li J, Cheng M, et al. 2019. Optimal drip fertigation management improves yield, quality, water and nitrogen use efficiency of greenhouse cucumber. Scientia Horticulturae, 243: 357–366.

Wang X X, Zhao F, Zhang G, et al. 2017. Vermicompost improves tomato yield and quality and the biochemical properties of

soils with different tomato planting history in a greenhouse study. Frontiers in Plant Science, 8: 1978, doi: 10.3389/fpls.2017.01978.

Wang Z, Liu Z, Zhang Z, et al. 2009. Subsurface drip irrigation scheduling for cucumber (*Cucumis sativus* L.) grown in solar greenhouse based on 20 cm standard pan evaporation in Northeast China. Scientia Horticulturae, 123: 51–57.

Warman P R, AngLopez M J. 2010. Vermicompost derived from different feedstocks as a plant growth medium. Bioresource Technology, 101(2): 4479–4483.

Wei Z, Liang Y, Yamada S, et al. 2009. Relation of soil microbial diversity to tomato yield and quality under different soil water conditions and fertilizations. Chinese Journal of Plant Ecology, 33(3): 580–586. (in Chinese)

Xu C, Leskovar D I. 2014. Growth, physiology and yield responses of cabbage to deficit irrigation. Horticultural Science, 41(3): 138–146.

Xu C, Mou B. 2016. Vermicompost affects soil properties and spinach growth, physiology, and nutritional value. HortScience, 51(7): 847–855.

Xue G, Lynne McIntyre C, Glassop D, et al. 2008. Use of expression analysis to dissect alterations in carbohydrate metabolism in wheat leaves during drought stress. Plant Molecular Biology, 67(3): 197–214.

Yadav L P, Malhotra S K, Singh A, et al. 2017. Effect of intercropping, crop geometry and organic manures on growth and yield of broccoli (*Brassica oleracea* var italica). Indian Journal of Agricultural Sciences, 87(3): 318–324.

Yang L, Zhao F, Chang Q, et al. 2015. Effects of vermicomposts on tomato yield and quality and soil fertility in greenhouse under different soil water regimes. Agricultural Water Management, 160: 98–105.

Zaller J G. 2007. Vermicompost as a substitute for peat in potting media, effects on germination, biomass allocation, yields and fruit quality of three tomato varieties. Scientia Horticulturae, 112(2): 191–199.

Zhang N, Ren Y, Shi Q, et al. 2011. Effects of vermicompost on quality and yield of watermelon. China Vegetables, (6): 76–79.

Zhao H T, Luo J, Shan Y H, et al. 2010. Effects of vermicompost organic-inorganic mixed fertilizer on yield and quality components of cucumber cultivated in greenhouse. Plant Nutrition and Fertilizer Science, 16: 1288–1293. (in Chinese)

Zhao H T, Li T P, Zhang Y, et al. 2017. Effects of vermicompost amendment as a basal fertilizer on soil properties and cucumber yield and quality under continuous cropping conditions in a greenhouse. Journal of Soils and Sediments, 17(12): 2718–2730.